A METHOD OF ELIMINATING FLICKER ON AN INTERLACED MONITOR

BACKGROUND OF THE INVENTION

The present invention relates to interlaced monitors and, more particularly, to a method of eliminating flicker on an interlaced monitor.

The human visual system retains an image for a fraction of a second after it is viewed. As a result of this "persistence of vision," a series of still images or frames that are presented at a sufficiently high rate will be integrated by the visual system into a "moving picture." However, if the time between images exceeds the period of persistence of vision, the image will not be successfully integrated and it will be perceived to flicker. Persistence of vision decreases as the image intensity increases and, therefore, bright images must be displayed more often to avoid flicker. For example, a frame rate of 24 frames per second may be adequate for a relatively dim motion picture suitable for a theater. However, computer monitors which are much brighter than motion pictures typically utilize frame rates of 72 frames per second or greater to avoid flicker.

Generally, computer monitors employ progressive scanning where a complete frame displayed with each scan. Progressive scanning at high frame rates is acceptable for computer monitors because the data bandwidth is relatively unrestricted. However, to limit the required broadcast bandwidth while presenting a relatively flicker free image, television utilizes an interlaced scan format. In the interlaced scan format, an image or frame is displayed by consecutively displaying two fields, each comprising every other scan line of the raster (frame). The fields are displayed at twice the frame rate. At least for images lacking fine detail, the fields contain sufficient information and are displayed with sufficient frequency to permit the visual system to integrate the two fields into a whole image having an acceptable level of "whole image" flicker. Television in the U.S. and monitors conforming to the NTSC format utilize a frame rate of 30 frames per second with a field rate of 60 fields per second. In Europe, a frame rate of 25 frames per second

is common for television.

While interlacing is effective in minimizing the bandwidth required for an acceptable level of "whole image" flickering, an interlaced image may include a number of undesirable artifacts that are the result of the fact that interlacing is not truly rapid repetition of the complete image. Vertically adjacent picture elements do not appear at the same time thereby creating jagged edges on moving objects. Horizontal edges may not match in successive scans creating misalignment or interline flickering (a shimmering effect). Flicker is particularly noticeable in images containing narrow horizontal lines such as computer generated "wire frame" drawings, character sets, and crosshatched areas. The sensation of flickering is the result of the high frequency variation of light intensity as the narrow line or sharp edge is repeatedly scanned, and is a function of the level of illumination and the spatial contrast between the line and its surroundings. Horizontal lines and sharp edges are particularly susceptible to flicker because the discontinuity of intensity that is the line or edge is generally parallel to the horizontal scan lines causing the intensity discontinuity to be repeated at the frame rate, not the field rate.

One method of reducing flicker is to perform a low pass filtering operation in the vertical direction. Filtering transverse to the scan lines reduces the local contrast of horizontal edges and eliminates spatio-temporal components of the image signal that could be visible as flicker. However, each image has a different level of detail and, therefore, a different propensity to flicker. Unfortunately, applying a single filter to all images results in loss of detail in images that would exhibit little tendency to flicker. Parulski et al, U.S. Patent No. 5,428,456, METHOD AND APPARATUS FOR ADAPTIVELY REDUCING INTERLINE FLICKER OF TV-DISPLAYED IMAGE recognize that certain images require more filtering than others and analyze image content before displaying the image to determine the appropriate level of filtering to apply to each image.

Differences in the level and type of detail and, therefore, the propensity to flicker varies within areas of an image as well as between images. Applying a

single filter to an entire image can destroy local vertical detail in areas of the image which would not have produced a flickering sensation. Campbell, U.S. Patent No. 5,019,904, SCAN CONVERTER WITH ADAPTABLE VERTICAL FILTER FOR SINGLE BIT COMPUTER GRAPHICS SYSTEMS, proposes to filter the image with a filter adapted to local conditions. The method is applied to pixels having two states displayed on a progressive scan monitor. Patterns of pixels known to cause flicker are identified by a pattern recognition generator and a filter coefficient is selected for application to the pixels of the pattern on the basis of the propensity of that pattern to cause flicker. Such pattern recognition is complex and computationally expensive, involving evaluation of patterns of pixels in each fixed area (six pixel (high) by three pixel (wide)) neighborhood of an image. Pattern recognition is more complicated and computationally expensive if applied to pixels capable of multilevel intensities. Further, the patterns identified as producing flickering on a progressive scan monitor do not have the same effect when rendered on an interlaced monitor.

What is desired, therefore, is a computationally inexpensive method of detecting and reducing flickering of horizontal lines or edges displayed on an interlaced monitor without unduly degrading image detail.

SUMMARY OF THE INVENTION

A first aspect of the present invention overcomes the aforementioned drawbacks of the prior art by providing a method of reducing flicker from a display presenting an interlaced image comprising filtering an adjustment pixel to reduce the flicker energy of the adjustment pixel to a level at least equal to a threshold flicker energy. The flicker energy is a function of the intensities of the adjustment pixel and another pixel vertically displaced from the adjustment pixel, the number of intensity transitions vertically displaced from the adjustment pixel, and the length of an approximately horizontal plurality of pixels of approximately equal intensity including the adjustment pixel. The sensation of flicker can be reduced or eliminated by reducing the flicker energy to an energy level equal to or less

than a threshold energy known to cause flicker.

A second aspect of the invention provides a method of reducing flicker from a display presenting an interlaced image by filtering an adjustment pixel to reduce the flicker contrast of the adjustment pixel to a contrast at least equal to a threshold flicker contrast. The flicker contrast is a function of the ratio of the difference and sum of the intensities of the adjustment pixel and another pixel vertically displaced from the adjustment pixel, a number of intensity transitions vertically displaced from the adjustment pixel, and a length of an approximately horizontal plurality of pixels of approximately equal intensity including the adjustment pixel.

Flicker is reduced on a display presenting an interlaced image by the steps of selecting an adjustment pixel in the image; and applying a filter to at least the adjustment pixel, the filter being adjusted, at least in part, on the basis of at least one of a function of the intensity of the adjustment pixel and the intensity of another pixel vertically displaced from the adjustment pixel; a function of a number of intensity transitions vertically displaced from the adjustment pixel; and a function of the length of an approximately horizontal plurality of pixels of approximately equal intensity including the adjustment pixel. The method is relatively inexpensive, computationally, requiring examination and adjustment of pixel intensity only at points likely to cause flicker. Since the method adaptively filters on a pixel by pixel basis, the detail in the remainder of an image is unaffected by the filtering to reduce flickering of a local line or edge.

The foregoing and other objectives, features and advantages of the invention will be more readily understood upon consideration of the following detailed description of the invention, taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates an image on an interlaced display used for psychophysical measurements of flicker propensity.

FIG. 2 is a graph of threshold flicker luminance as a function of the number and the length of horizontal lines in a test pattern.

FIG. 3 is a graph of normalized threshold flicker energy as a function of the number and length of horizontal lines in a test pattern.

FIG. 4 is a graph of normalized threshold flicker energy as a function of background luminance.

FIG. 5 is a graph of normalized threshold flicker contrast as a function of the number and length of horizontal lines in a test pattern.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Thin horizontal lines and edges, particularly sharp edges, are vulnerable to flickering when displayed on a display presenting an interlaced image. A horizontal line or edge is produced by a discontinuity of intensity or luminance between a plurality of pixels of approximately equal intensity arrayed horizontally and the vertically adjacent pixels of the background. As the horizontal scan lines are generated on the display all or part of the pixels in an approximately horizontal row of pixels (a horizontal line) may be scanned in a single field of the interlaced image. As a result, the intensities of the pixels of a line or edge will vary with a period that exceeds the period of the visual system's persistence of vision, and the line or edge will be perceived to flicker.

Referring to FIG. 1, to identify factors influencing the perception of flicker, the present inventor performed psychophysical measurements using patterns of horizontal lines displayed on an interlaced monitor 3. Patterns of horizontal lines 2 were displayed on a background 4 of uniform intensity inset in a surround 6 having a different intensity than the background 4. With the intensity of the background 4 and viewing distance held constant, the intensity of the lines 2, as measured by their luminance, was varied until a viewer perceived the onset of flickering of the lines 2. The length 8 and the number of lines 2 in the pattern, the intensity of the background and the viewing distance were independently varied in several series of tests.

FIG. 2 summarizes the results of a series of tests where the luminance of the background and the viewing distance were held constant while the number of lines in the pattern and their lengths were varied. The luminance at the threshold of flicker 20 is plotted on the vertical axis and the length of the line 22 in pixels is plotted on the horizontal axis. Based on such tests, the present inventor was surprised to observe that the difference between the luminance of the background 24 and the luminance of the lines 26 and 28 at the onset of flicker is a function of the number of lines in the pattern, and the length of the line 22. The number of lines and/or their length may be used as a basis for the reduction of flicker. Luminance values of the background and the lines are added in a signed manner. When the lines of the pattern are brighter (more luminous) than the background, the line luminance at the threshold of flicker 26 is greater than the background luminance 24. When the lines are darker than the background, the luminance of the lines subtracts from the luminance of the background, and the line luminance at the threshold of flicker 28 is less than the background 24.

As illustrated in FIG. 2, as the length of the line increases the difference in intensity between the line and background at which flicker will be perceived decreases. On the other hand, for a fixed line length, the intensity difference at the threshold of flicker perception decreases as the number of lines is increased. The tests revealed little change in the flicker threshold for numbers of lines in a pattern greater than four. These results are likely due to spatial summation performed by the visual system when several spatially separated neurons are simultaneously stimulated. Tests with different viewing distances and levels of background intensity produced similar results.

This test data can be normalized by the following formula:

$$Flicker\ Energy = \log\left(\frac{Lline}{Lbackground}\right)\ \text{(Number of Edges)}\ \left(\frac{length}{length + \text{end effect}}\right)$$

where:

$Lline$ = the luminance of the line

$Lbackground$ = the luminance of the background

Number of edges = number of luminance transitions in a vertical column through the pattern of lines or edges (number of lines + 1)
length = length of the line or edge (number of pixels)
end effect = a factor compensating for the horizontal summation properties of the human retinal system

The flicker energy accumulates the total energy of the horizontal edges of the pattern of lines and corresponds to the energy in one receptor field in the retina.

FIG. 3 illustrates the flicker energy of the data of FIG. 2, normalized in accordance with the equation above. Flicker energy 30 is plotted on the vertical axis and line length 32 is plotted along the horizontal axis. The background luminance 31 is the vertical ordinate in the normalized energy plot. Lines brighter than the background result in positive flicker energies 34 and lines darker than the background result in negative flicker energies 36. The flicker energy at the threshold of flicker is relatively invariant for all combinations of the numbers of lines and lengths for both (1) brighter lines on a darker background 34 and (2) darker lines on a lighter background 36. Tests in which viewing distances were varied produced similar results. FIG. 4 illustrates the flicker energy 40 (vertical axis) as a function of the background luminance 42 (horizontal axis) and the number of lines in the pattern for brighter lines 44 and darker lines 46.

The use of a logarithmic function to compute the scaled or flicker energy is appropriate when background intensity is significant (above 40 cd/m^2). As an alternative, a flicker contrast, as follows, may be used to determine the onset of flickering of a pattern of horizontal lines:

$$\text{Flicker Contrast} = \left(\frac{L_{line} - L_{background}}{L_{line} + L_{background}}\right)(\text{Number of edges})\left(\frac{\text{length}}{\text{length} + \text{end effect}}\right)$$

The flicker contrast utilizes the common metric of contrast, the ratio of intensities, to achieve qualitatively the same result while being simpler to compute and avoiding singularities at low background or line intensity values. Referring to FIG. 5, the flicker contrast 50 (vertical axis) exhibits the same invariance as a

function of line length 52 (horizontal axis) and number of lines per pattern as is exhibited by the flicker energy.

The end effect term of the flicker energy and flicker contrast equations compensates for the spatial summation performed by the eye's retinal system in integrating the effect of edges (line ends) when the visual field representing the line extends laterally to involve multiple visual receptors. End effect values were determined by the nonlinear least squares best fit to the test data which yielded the smallest variation in the resulting flicker energy for all combinations of line numbers and lengths at a particular background luminance and viewing distance. Exemplary values of the end effect for lines brighter than the background and lines darker than the background at different levels of background luminance are:

End effect (number of pixels)				
Background luminance (cd/m^2)	48	96	154	192
Brighter lines / darker background	8.9	6.3	5.0	4.3
Darker lines / brighter background	44.8	16.1	9.2	6.3

However, the fit to the test data is not strongly dependent on the exact value of the end effect parameter and an end effect constant may be used. End effect constants of six (6) for lines brighter than the background and twelve (12) for lines darker than the background have been determined to produce satisfactory results.

From the psychophysical investigation, the present inventor concluded that reducing flickering of horizontal lines or edges displayed on a monitor presenting an interlaced image could be optimally accomplished by filtering the signal for a pixel with a filter specifically selected to reduce the flicker energy or the flicker contrast of that pixel below the threshold energy or contrast necessary for flickering. Applying filtering on a pixel-by-pixel basis permits details in an image locality which might result in flickering to be addressed with a level of filtering appropriate to prevent flickering without disturbing details, which would not flicker, in the remainder of the image. An adjustment pixel which is a member of a

plurality of pixels of approximately equal luminance and arranged for approximately horizontal presentation on the display (a horizontal line) is identified. The luminance of a background pixel vertically displaced, either above or below, to the adjustment pixel is determined. Likewise, the length of the horizontal line of pixels and/or the number of intensity transitions vertically above and below the adjustment pixel is determined. The flicker energy or the flicker contrast is computed and compared to a threshold flicker energy or contrast, as appropriate. A filter having coefficients that will reduce the luminance of the adjustment pixel sufficiently to cause the flicker energy or flicker contrast to be less than the threshold energy or contrast can be selected and applied to the adjustment pixel.

The filtering can be applied in several ways. For example, the flicker energy can be computed using the original luminance values for all pixels and an output image obtained by filtering the original luminance values to yield a final image. Alternatively, filtering can be applied on a pixel-by-pixel basis with the computation of flicker energy or contrast adjusted at each pixel to reflect prior adjustments of intensity made as a result of processing earlier pixels. Further, filtering can be performed iteratively, with minimal filtering applied at each iteration until the potential for flickering is eliminated.

The psychophysical investigation did disclose considerable variation in the flicker threshold between viewers. As a result of viewer-to-viewer variation, a calibration or adjustment step may be included in the method. The adjustment would permit a viewer to adjust the level of filtering to reduce flicker in "hot spots." The magnitude of the calibration adjustment may then be used to determine the appropriate level of filtering for other combinations of line length, pattern, or contrast. For example, a viewer selected filter level for four lines, eight pixels in length on a black background might be used to ascertain the appropriate flicker energy threshold for all line lengths and numbers for the same background luminance and, by extrapolation, other luminance levels as well.

All the references cited herein are incorporated by reference.

The terms and expressions that have been employed in the foregoing specification are used as terms of description and not of limitation, and there is no intention, in the use of such terms and expressions, of excluding equivalents of the features shown and described or portions thereof, it being recognized that the scope of the invention is defined and limited only by the claims that follow.